MITSUBISHI ELECTRIC

SiC Lecture Series

6. Growth technology of SiC bulk single crystals

Growth technology of SiC bulk single crystals

SiC does not have a liquid phase with a stoichiometric composition (Si:C = 1:1) at atmospheric pressure. Therefore, the method commonly used for Si, which involves using a melt as the raw material, cannot be used for the production of SiC bulk single crystals. Instead, the sublimation method of Physical Vapor Transport (PVT) is employed. In the sublimation method, SiC powder, as the raw material, and a SiC substrate, as the seed crystal, are placed inside a graphite crucible. A temperature gradient is applied so that the temperature on the SiC powder side is slightly higher, and the entire system is maintained at 2000-2500°C. The sublimation method using SiC seed crystals is called the modified Lely method and is widely used for the production of SiC substrates.

Figure 1 shows a schematic diagram of the SiC crystal growth method using the modified Lely method. In a graphite crucible heated to over 2000°C, SiC powder sublimates into molecules such as Si_2C, SiC_2, and Si, which are then supplied to the surface of the seed crystal. The supplied atoms move around on the surface of the seed crystal, are incorporated into sites forming the crystal, and the SiC bulk single crystal grows. Typically, Ar in a reduced pressure state is used as the ambient atmosphere, and nitrogen gas is added for n-type doping.

Although the sublimation method is widely used for the production of SiC single crystals, some issues become evident when compared to the melt-based method used for Si single crystal growth. These issues include a slower growth rate and the presence of many dislocations in the crystal, though gradual improvements in quality are steadily being made.

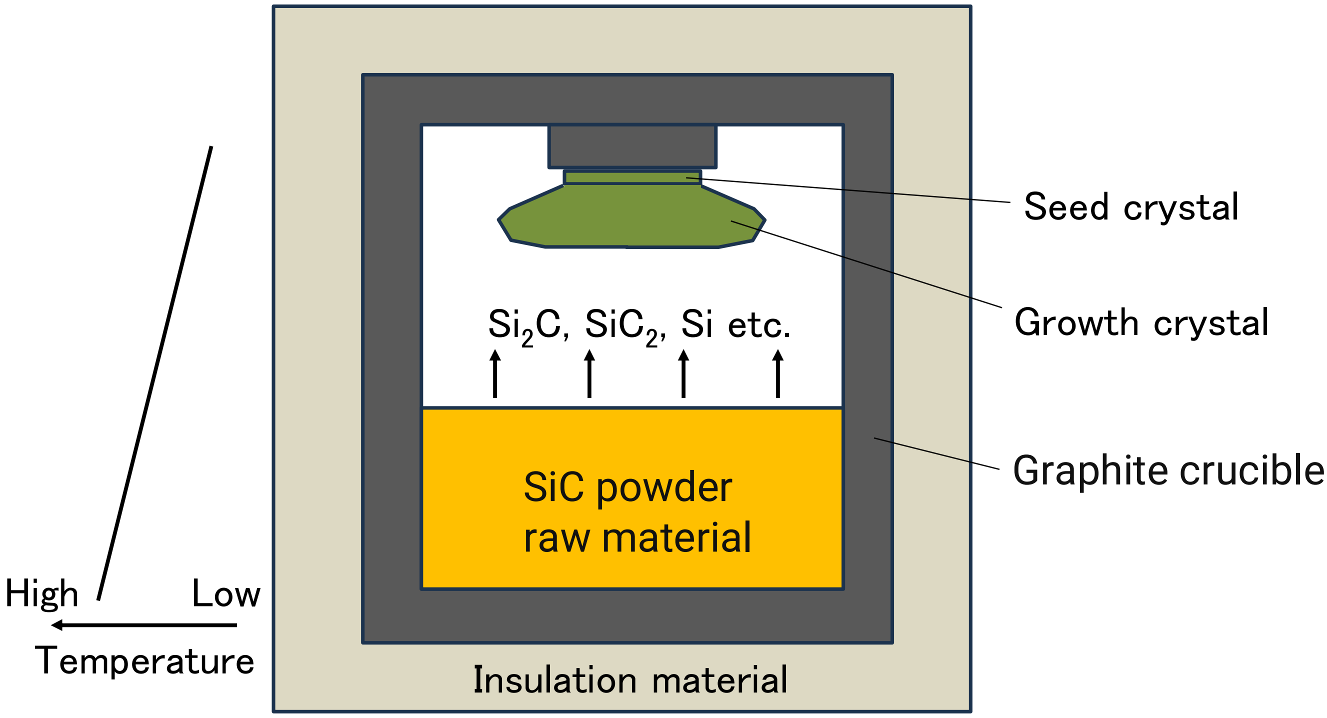

Figure 1 Schematic of SiC Bulk Single Crystal Growth by Sublimation Method

Attempts to produce SiC bulk single crystals using growth methods other than the sublimation method include liquid phase growth from a solution and high-temperature Chemical Vapor Deposition (CVD) methods. Figures 2 and 3 show schematic diagrams of the solution growth method and high-temperature CVD method for SiC single crystals, respectively.

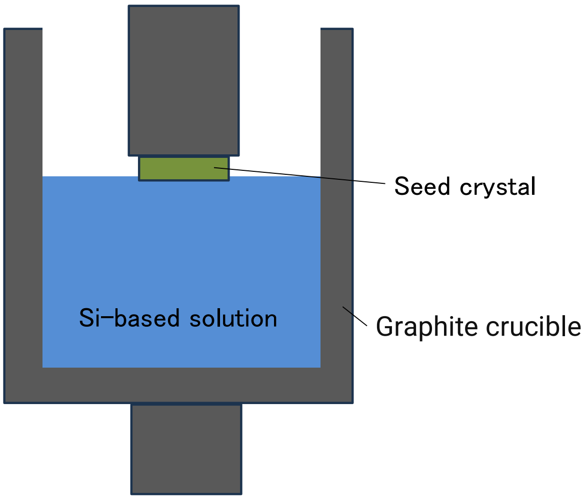

Figure 2 Schematic of Solution Growth Method for SiC Bulk Crystals

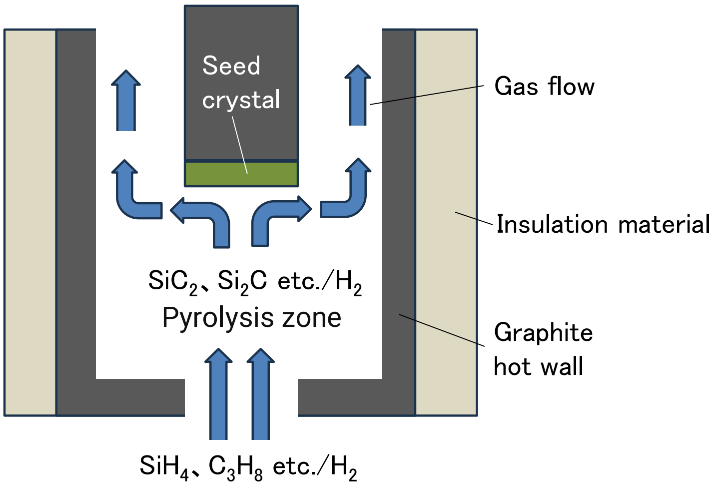

Figure 3 Schematic of High-Temperature CVD Method for SiC Bulk Crystals

First, the solution growth method is described below. The solubility of carbon in a silicon solvent is very low. Therefore, various elements such as Ti and Cr are added to the solvent to improve the solubility of carbon. Carbon is supplied from a graphite crucible, and SiC single crystals grow on the surface of a seed crystal maintained at a slightly lower temperature. The growth temperature is often set between 1500 and 2000°C, which is lower than that of the sublimation method. This method has reported a growth rate of several hundred μm/h.

One advantage of the solution growth method for SiC is that when growing crystals in the [0001] direction, dislocations extending in the [0001] direction can be bent orthogonally and expelled from the crystal through the sidewalls. Screw dislocations extending in the [0001] direction are currently present at high densities in SiC crystals and are sources of leakage current in devices. However, a significant reduction in the density of screw dislocations has been reported in SiC crystals grown using the liquid phase growth method. Challenges in solution growth include increasing the growth rate, elongating the grown crystals, and improving the surface morphology of the crystals.

Next, we consider the growth of SiC single crystals using the high-temperature CVD method. In this method, under a reduced-pressure hydrogen atmosphere, SiH_4 is supplied as the Si source and C_3H_8 as the C source, and a single crystal SiC layer is grown on the surface of a SiC substrate maintained at a high temperature (usually above 2000°C). The source gases introduced into the growth furnace decompose into molecules such as SiC_2 and Si_2C in a thermal decomposition zone surrounded by a hot wall, and these molecules are supplied to the surface of the seed crystal to grow single crystal SiC.

Advantages of the high-temperature CVD method include the ability to use high-purity source gases, precise control of the C/Si ratio in the vapor phase, which is an important growth parameter affecting defect density, and relatively high growth rates of 1 mm/h or more for bulk SiC growth. On the other hand, disadvantages include the significant maintenance burden due to the large amount of reaction products adhering to the inside of the growth furnace and exhaust lines, and the generation of particles in the gas phase that can be incorporated as foreign substances into the crystal.

The high-temperature CVD method is promising for producing high-quality SiC bulk crystals, and development continues towards achieving lower costs, higher productivity, and lower dislocation densities compared to the sublimation method.

Also of note is the repeated a-face (RAF) method, a sublimation method for producing SiC bulk single crystals with fewer crystal defects. In the RAF method, a seed crystal with a face orientation orthogonal to the [0001] direction is cut from a crystal grown in the [0001] direction, and SiC single crystals are grown on it. Furthermore, a seed crystal with a face orientation orthogonal to the growth direction is cut, and SiC single crystals are grown on it. By repeating this cycle, dislocations are expelled from the crystal, resulting in SiC bulk single crystals with fewer defects. SiC single crystals produced by the RAF method have been reported to have dislocation densities one to two orders of magnitude lower than those of conventional crystals.

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